AD-A192 126 DYNAMIC CONSOLIDATION OF METAL POWDERS(U) LAWRENCE LIVERMORE NATIONAL LAB CA W H GOURDIN 25 JAN 88 ARO-18211.14-MS MIPR-ARO-106-86 1/1

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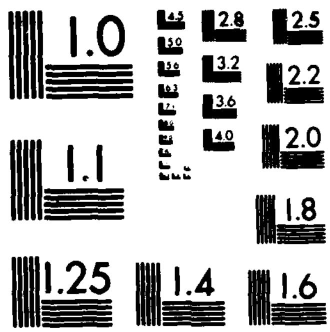

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARO 18211.14-MS
6a. NAME OF PERFORMING ORGANIZATION Lawrence Livermore National Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U. S. Army Research Office
6c. ADDRESS (City, State, and ZIP Code) P. O. Box 808 Livermore, CA 94550	7b. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U. S. Army Research Office 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MIPR ARO 106-86
8c. ADDRESS (City, State, and ZIP Code) P. O. Box 12211 Research Triangle Park, NC 27709-2211	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
Dynamic Consolidation of Metal Powders (Unc)

12. PERSONAL AUTHOR(S) William H. Gourdin

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 9/14/81 TO 9/30/88	1988, January 25	3

16. SUPPLEMENTARY NOTATION The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We have studied the shock wave consolidation of copper, 4330 steel and aluminum+6% silicon powders. We measured the Hugoniots of the unsintered powders using piezoresistive pressure sensors as well as impedance matching techniques and found that they can be well described by available models for pore collapse. An elementary model for the surface heating was developed based on the flux of energy at the interfaces between powder particles during compaction. This model was found to agree quantitatively with observations of localized microstructural modifications in recovered specimens. We found that most of the energy of the compaction shoc is deposited at the particle interfaces and that powder particle morphology and specific surfa area are important variables. Localized thermal modifications can be either solid state trans formations or surface melting and rapid cooling can produce metastable structures. Knowledge of the shock history is essential to the interpretation and control of the consolidated micro-structure. We have produced and tested consolidated aluminum+6% silicon that has tensile properties comparable to those of wrought material.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
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SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ARO 18211.14-MS

DYNAMIC CONSOLIDATION OF METAL POWDERS

FINAL REPORT

WILLIAM H. GOURDIN

JANUARY 25, 1988

U. S. ARMY RESEARCH OFFICE

SLCRO-IP-L-18211-MS

LAWRENCE LIVERMORE NATIONAL LABORATORY

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Problem studied: The objective of this research was to characterize and understand the shock wave consolidation of metal powders. A primary concern was the assessment of this process as a means of consolidating rapidly solidified powders without destroying the unique microstructures obtained during the rapid solidification processing.

Principal accomplishments: The conclusions of this work have been given in detail in the publications listed subsequently, and only a summary outline is presented here. More information can be obtained from the publications cited by number at the end of each listing.

1. Measured the shock Hugoniots of unsintered copper, 4330 steel and rapidly solidified aluminum + 6% silicon powders and showed that ductile materials can be described by the "$p-\alpha$" model of pore collapse. Generally, irregular, low packing density powders achieve full density at the lowest stresses for any given material; likewise spherical powders required higher stresses [1].

2. Developed an elementary model for surface heating based on the flux of energy at the surfaces of powder particles during the rise of the compaction shock. This model was shown to agree with experimental observations of the fraction of localized material modification. It was concluded that: (1) The specific area of the powder and the rise time of the shock are important quantities which, with the net specific energy, determine the surface temperatures achieved; (2) Most of the energy of the shock is deposited at powder particle surfaces; (3) For given compaction conditions, the highest surface temperatures are obtained in powders of moderate packing density and small specific area; (4) Heating and cooling rates at particle surfaces can be extremely high (10^8 - 10^{11} C/s), and metastable structures may form from locally melted or modified material; (5) For monosized spherical powders, the energy flux is independent of particle size, and the surface temperature increases with particle size [2-4].

3. Characterized the microstructures of compacts of copper, 4330 steel and aluminum + 6% silicon, and concluded that: (1) Localized thermal modifications can take the form of solid-state phase transformations (martensite in the steel) or surface melting (Al + 6% Si); (2) Knowledge of the shock history is essential to the interpretation and control of the consolidated microstructure; (3) Residual temperatures following compaction at stresses sufficiently high to induce desired surface modifications may produce undesirable changes in the final compact microstructure. The minimum powder size is fixed by the maximum residual temperature; (4) Confirmed the melting and rapid resolidification of material as a result of severe local deformation [5,6].

4. Produced consolidated aluminum + 6% silicon with tensile properties comparable to those of wrought material [6,8].

5. Showed that carbon piezoresistive sensors could be used to determine the stresses during the consolidation of unsintered metal powders [7].

6. Wrote a review (by invitation) of the dynamic consolidation of metal powders [8].

7. Studied particle size effects in samples of explosively compacted stainless steel [9].

8. Performed cursory, low and high pressure compaction experiments on copper-zirconium rapidly solidified powder. Complete melting was observed at 60 GPa [10].

Publications:

1. W. H. Gourdin and S. L. Weinland, "Hugoniot Measurements on Unsintered Metal Powders," in Shock Waves in Condensed Matter - 1983, J. R. Asay, R. A. Graham, and G. K. Straub, editors, Elsevier, N.Y., 1984, pp 99-102.

2. W. H. Gourdin, "Energy Deposition and Microstructural Modification in Dynamically Consolidated Metal Powders," J. Appl. Phys. 55, 172-181 (1984).

3. W. H. Gourdin, "Prediction of Microstructural Modification in Dynamically Consolidated Metal Powders," in Shock Waves in Condensed Matter - 1983, J. R. Asay, R. A. Graham, and G. K. Straub, editors, Elsevier, N.Y., 1984, pp 380-382.

4. W. H. Gourdin, "The Analysis of Localized Microstructural Changes in Dynamically Consolidated Metal Powders," in High Energy Rate Fabrication - 1984, I. Berman and J. W. Schroeder, editors, The American Society of Mechanical Engineers, N.Y., 1984, pp 85-92.

5. W. H. Gourdin, "Local Microstructural Modification in Dynamically Consolidated Metal Powders," Met. Trans. A, 15A, 1653-1664 (1984).

6. J. E. Smugeresky and W. H. Gourdin, "Metallurgical Analysis of Dynamically Compacted Monosized Aluminum-6% Silicon Powders," in Metallurgical Applications of Shock-wave and High-strain-rate Phenomena, L. E. Murr, K. P. Staudhammer and M. A. Meyers, editors, Marcel Dekker, N.Y., 1986, pp 107-128.

7. W. H. Gourdin and S. L. Weinland, "Performance of Piezoresistive Carbon Sensors in Contact with Porous Materials," Rev. Sci. Instrum., 57, 1422-1426 (1986).

8. W. H. Gourdin, "Dynamic Consolidation of Metal Powders," Progress in Materials Science, 30, 39-80 (1986).

9. J. E. Smugeresky, T. J. McCabe, and R. A. Graham, "Effect of Powder Particle Size and Shape on the Microstructure of Explosively Compacted Stainless Steel," to appear in the Proceedings of the APS Topical Conference on Shock Waves in Condensed Matter, July 20-23, 1987, Monterey, California.

10. W. J. Nellis, W. H. Gourdin and M. B. Maple, "Shock-induced Melting and Rapid Solidification," Ibid.

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Contract/Grant Number: SLCRO-IP-L-18211-MS

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